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TITLE: LAMPF NUCLEAR CHEMISTRY DATA ACQUISTION SYSTEM

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LAMPF NUCLEAR CHEMISTRY DATA ACQUISITION SYSTEM

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ABSTRACT

The LAMPF Nuclear Chemistry Data Acquisition System (DAS) is designed to provide both real-time control of data acquisition and facilities for data processing for a large variety of users. It consists of a PDP-11/44 connected to a parallel CAMAC branch highway as well as to a large number of peripherals. The various types of radiation counters and spectrometers and their connections to the system will be described. Also discussed will be the various methods of connection considered and their advantages and disadvantages. The operation of the system from the standpoint of both hardware and software will be described as well as plans for the future.

THE NUCLEAR CHEMISTRY LABORATORY

The Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF) is a medium-energy (800-MeV) proton linear accelerator.[1] Nuclear chemistry experiments may be conducted at LAMPF using either the direct proton beam or any of the secondary beams of muons, pions, or neutrons. In activation experiments, the targets irradiated in any of these beams may be transported by vehicle or via a pneumatic transfer system to the Nuclear Chemistry Laboratory (NCL) where they are analyzed. The NCL consists of four chemistry laboratories, five counting rooms, and office space for staff and visiting scientists (see Figure 1). The basement area may also be used for counting equipment.

COUNTING SYSTEMS

A large variety of radiation counting systems are available in the counting rooms of the NCL. These systems can be separated into two types, counters and spectrometers. Counters are systems that produce one or a few values as the output from the measurement on a radioactive sample. One type of system in this category includes propane-gas-flow β-particle proportional counters (Figure 2) and methane-gas-flow α-particle proportional counters (Figure 3). A special case of the β-particle proportional counters is the low background counters shown in Figure 4. These units are mounted inside a much thicker than usual shield and have a 12.7 cm × 12.7 cm NaI(Tl) detector mounted above the proportional counter chamber operated in anticoincidence mode to further reduce the cosmic-ray background. All of these counting systems produce a single value as the output at the end of a counting period.

Another single counting system is a 7.6 cm × 7.6 cm NaI(Tl) γ-ray counter that is gated to count only pulses corresponding to a specific energy region (Figure 5). These regions may include only 511-keV positron-annihilation γ rays or the 1369-keV and 2754-keV γ rays from ^{24}Na. This counter is used primarily for γ-ray-emitting samples that are too weak to be measured with Ge(Li) γ-ray spectrometers.

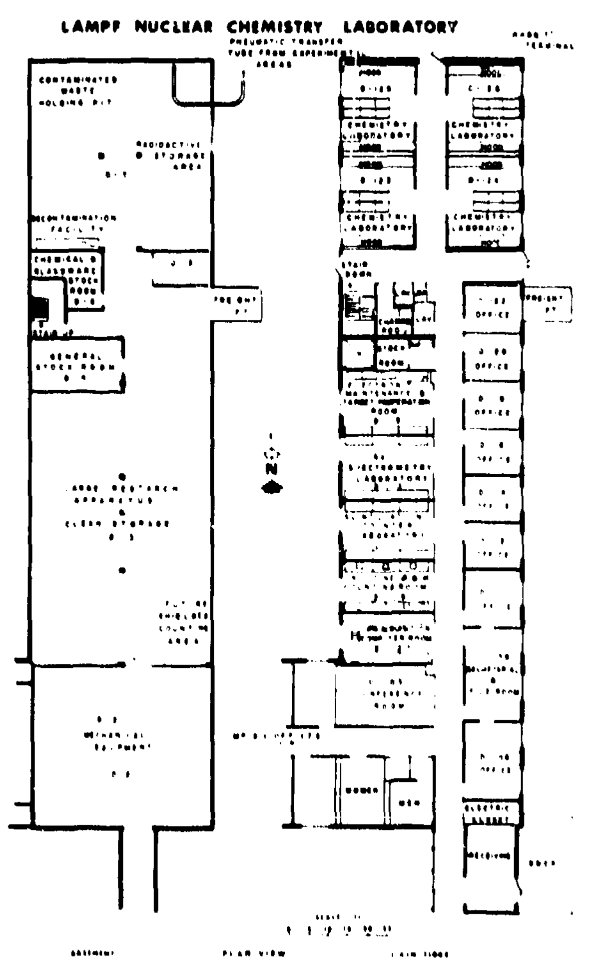

Figure 1. A plan view of the Nuclear Chemistry Laboratory at LAMPF.

*This work was supported by the U. S. Department of Energy.

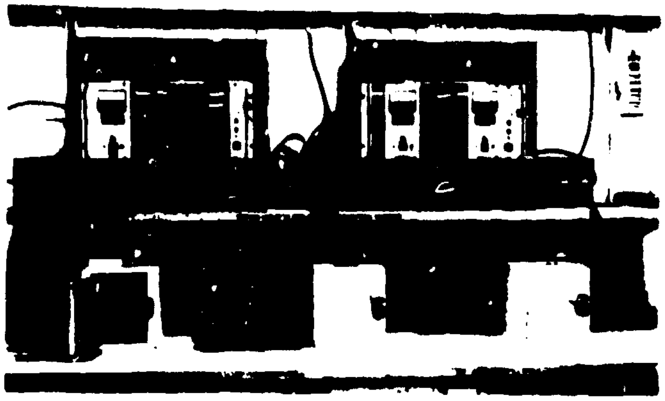

Figure 2. Propane-gas-flow β-proportional counters and associated electronics.

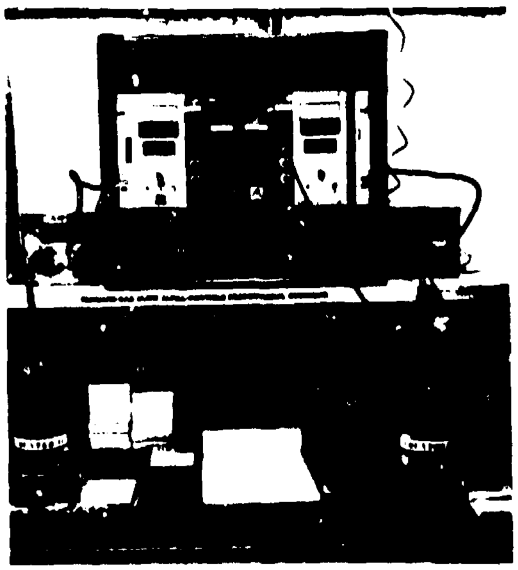

Figure 3. Methane-gas-flow α-proportional counters and associated electronics.

Another type of counting system is the coincidence system. These systems contain two independent counters facing each other and are connected to a coincidence module. As a result, three values are output at the end of each counting period (two singles plus the coincidence output). We have two different types of coincidence counting systems. One is a β-particle-γ-ray coincidence system shown in Figure 6. This is used to determine absolute activities of samples. In particular, it has a 7.6 cm × 7.6 cm NaI(Tl) detector gated on the annihilation γ ray and a photomultiplier coupled to a plastic scintillator to count β particles. This is used exclusively for determining the absolute disintegration rate of the pure β^+-emitter ^{11}C, via

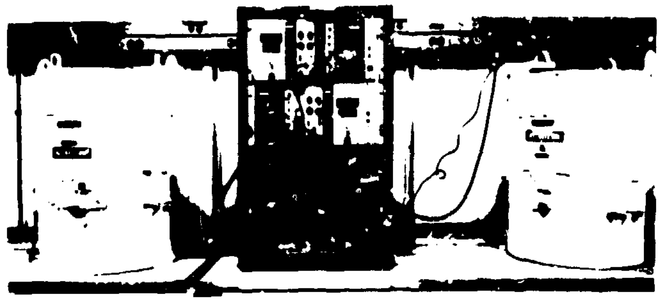

Figure 4. Low background β-proportional counting systems.

Figure 5. NaI(Tl) γ-ray spectrometer located inside spherical shield. A NaI(Tl) well-type γ-ray spectrometer is located in the square shield.

β^+-511-keV-γ-ray counting. Figure 7 shows the other type of coincidence system, a positron annihilation counter. It has two 7.6 cm × 7.6 cm NaI(Tl) detectors each gated on the annihilation γ ray. This system, as well as all of the single counters, are used to determine relative counting rates. By calibrating these with standards, one is able to convert relative counting rates to absolute decay rates.

The other major class of counting systems is the spectrometer. These systems produce a spectrum of counts versus energy, normally over 1024 to 4096 channels of a multichannel analyzer (MCA), as output instead of one or a few numbers. Si(Li) surface-barrier detectors in vacuum chambers are used for α-particle spectra and are shown in

Figure 6. β-particle-γ-ray coincidence counter.

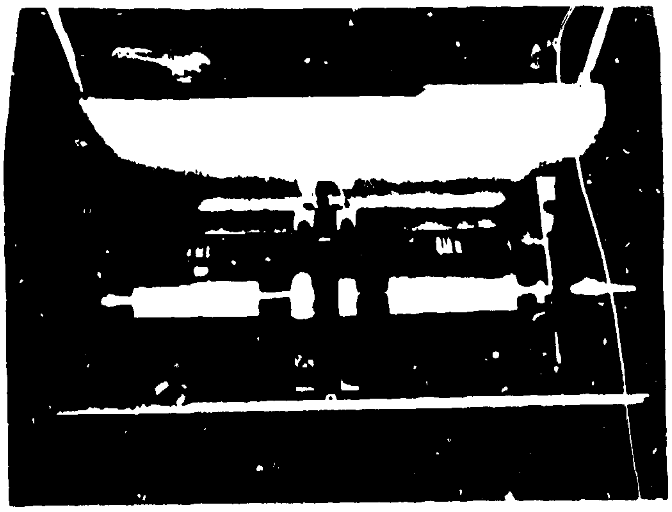

Figure 7. Two 7.6 cm × 7.6 cm NaI(Tl) detectors used in coincidence mode as a positron annihilation counter.

Figure 8. Gamma-ray spectrometry can be performed with either NaI(Tl) spectrometers or Ge(Li) spectrometers (Figure 9). Because of the much better resolution of the Ge(Li) spectrometers, the NaI(Tl)-based systems are normally used in the gated counter mode described earlier.

The spectrometers normally have a shelf system so that samples can be placed at various fixed distances for which the efficiency of the detector was calibrated. However, the samples have to be changed manually, as with the various counter systems. Since the samples for the γ-ray spectrometers have generally been numerous and contain radioactive species of medium-to-long half-life, this changing of samples can become very tedious. Therefore, we have constructed the automatic sample changer shown in Figure 10 for use with a Ge(Li) spectrometer. It has a 24-position

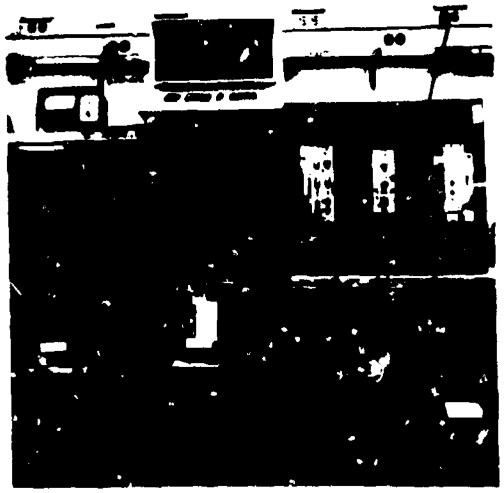

Figure 8. Solid-state α-particle spectrometers and their associated electronics.

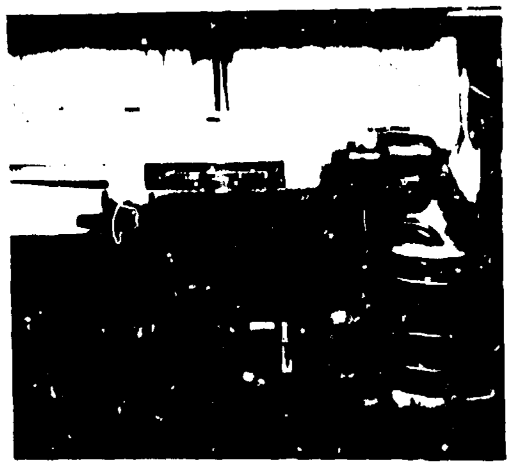

Figure 9. Ge(Li) spectrometer system with mercury-filled shield.

wheel for samples and a 12-position shelf stop system.

All these counting systems can be operated as stand-alone manual or semi-automatic counting systems without direct access to a computer. The counters have scalers and timers for output and control, and portable printers are available for automatic recycling of the systems. Magnetic tape units are connected to the multichannel analyzers that can be used with the various spectrometers. The sample changer has a manual control unit, which does not have a stand-alone programmable capability.

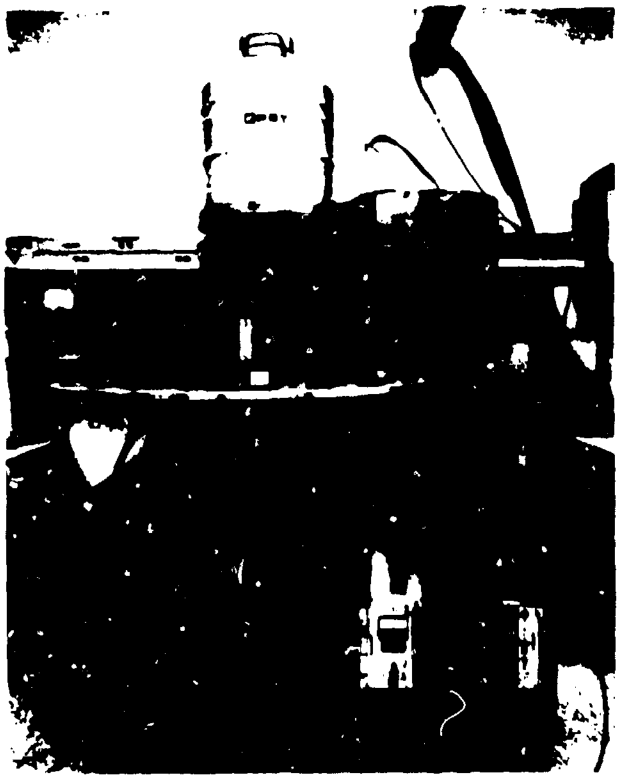

Figure 10. Twenty-four position automatic sample changer with a Ge(Li) spectrometer.

PHILOSOPHY OF DESIGN

In 1973 when the design of this system was begun, it was known what types of counting equipment were to be supported, since this counting system is a small version of one already existing in our main Radiochemistry Laboratory. Many scalers and timers are needed for the α- and β- proportional counters, the β-γ coincidence counter, and the positron annihilation counters. Also, a number of MCAs are needed for the various spectrometers.

One way to provide the functions served by these units is by direct connection of the outputs of the counters and spectrometers to Unibus interfaces. The computer would then have to respond to each event from each counter and ADC as well as to keep an elapsed time clock for each input. This obviously would easily overload the computer and therefore not be feasible.

By providing scalers, timers, and multichannel analyzers as units separate from the computer, most of the direct data acquisition load would be taken off the main computer. The computer would only need to set the various counters to the desired count length and then read out the data when the counters were done counting. The internal bookkeeping would be greatly simplified and more counters could be supported.

SELECTION OF CAMAC

With the decision made to interface external collection units to the computer, the next step was to find the best way to do it. Several manufacturers of nuclear counting equipment had proprietory busses to connect their modules together and to a printer or teletype. These busses are rather slow and have limited capability for computer control of the counting modules.

Connecting these modules directly to the computer bus itself is another possibility. However, due to the large number of modules involved and the fact that they are in four counting rooms, several Unibus repeaters would be needed. Also, a large number of noncounting peripherals are already heavily loading the bus. Therefore, this option is unuseable.

The only apparent remaining choice is the CAMAC Branch Highway.[2] The units used in a CAMAC system are modular and therefore very portable, similar to existing NIM units. Since there are many standard, off-the-shelf units, they provide great flexibility in configuring and reconfiguring a system. This system is also easily expandable.

With these advantages come several disadvantages. Although many of the units we needed were standard NIM designs, no equivalent CAMAC modules existed. As a result, most of our CAMAC modules were custom designed.

Associated with this is the problem of having them repaired since they were the only ones of their kind. Repairs are performed by a laboratory in-house electronics maintenance group with some consultation with the manufacturer. Since other people have similar needs for their counting systems, some of these CAMAC modules are now available commercially, and thus more support and documentation are available when problems occur.

An obvious second problem is software. Since the CAMAC modules are custom designed, the software must also be custom designed. A large amount of effort by LAMPF programmers has gone into the data acquisition package called "Q".[3] This set of programs provides the user a very powerful tool with which to control his CAMAC system. Its primary disadvantage is that it is a single-user system. Since we have to provide counting facilities for several users at a time, we must use a subset of "Q". This subset is slow, one CAMAC command at a time, and is not interrupt driven. As a result, reading out a multichannel analyzer takes a few minutes instead of a few seconds.

RS-232[4] was available at the time the system was designed. However, it was specified for a maximum cable length of 50 feet, and the MCAs were as far as 100 feet from the cpu. Also, at that time the use of RS-232 was primative: namely, a full dump of an MCA memory in digits with no flow control and only simple control of the operation of the MCAs. This method is currently used to connect some of the MCAs to the CAMAC highway and thereby to the cpu.

GPIB,[5] also known as IEE-488, was not available then. Even today there are no modules available of the type we use, and this system is not oriented to this type of application.

CAMAC SYSTEM

Figure 11 is a schematic of the DAS CAMAC branch highway. The CAMAC crates in each of the two counting rooms in which scaler counting is

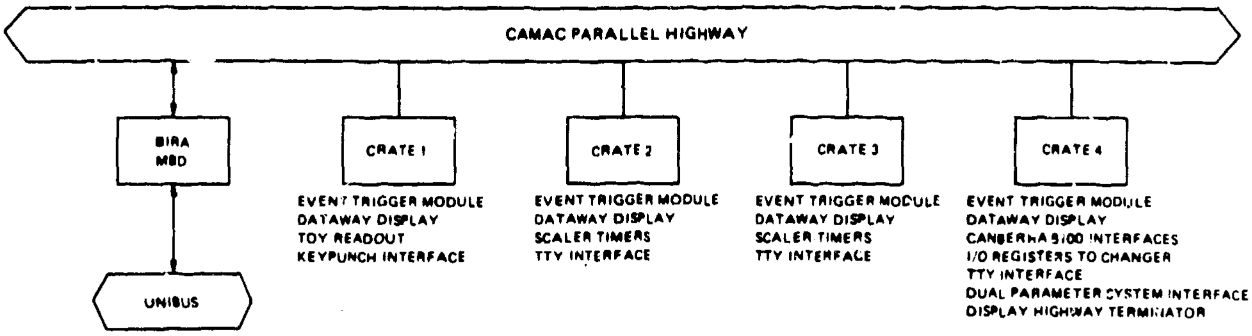

Figure 11. The CAMAC branch highway portion of the DAS.

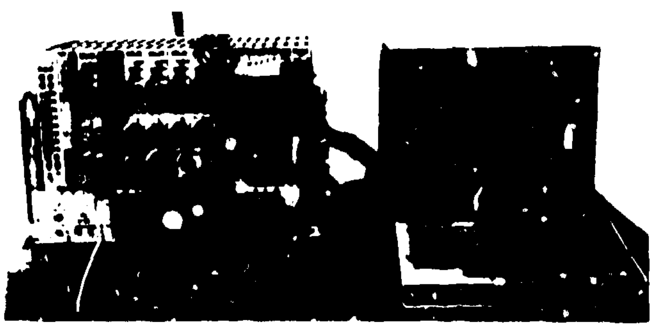

Figure 12. A CAMAC crate containing several scaler-timers and a TTY-to-CAMAC interface as well as standard modules.

performed have similar contents. One of these crates is shown in Figure 12. The crate contains several BiRa Model 2101 Dual Scaler-Timers.[6] Each of these units has two independent scalers and two independent timers. The output of each timer can be used to control one or more scalers so that all scalers connected to a particular counter can be started and stopped simultaneously. Each crate has enough scalers to operate all counters in that room at the same time.

In addition to the scaler-timers, each of these crates has one or more CAMAC-to-TTY interfaces. These are used for control of and for transmitting spectral output from small 2048-channel MCAs used for α-particle spectrometry and NaI(Tl)-γ-ray spectrometry. These MCAs are also used to replay data cassettes produced when these MCAs are used in the experimental areas in multiscaler mode as beam intensity monitors.

In the γ-ray spectroscopy counting room, there are a number of different CAMAC modules used. In Figure 13, a typical configuration of this crate is shown. As in the other crates, this crate contains an Event Trigger module[7] and a dataway display module. Since this is normally the end of the highway, a display highway terminator is included.

This crate has the interfaces to connect the various types of MCAs used to the branch highway. Some of the MCAs required the design and construction of special units for connecting to the branch highway and for performing the BCD-to-binary conversion of the data as it is passed from the MCA to the branch highway. Other MCAs are connected through standard TTY-to-CAMAC interfaces. The Dual Parameter Data Acquisition System[8] is connected to

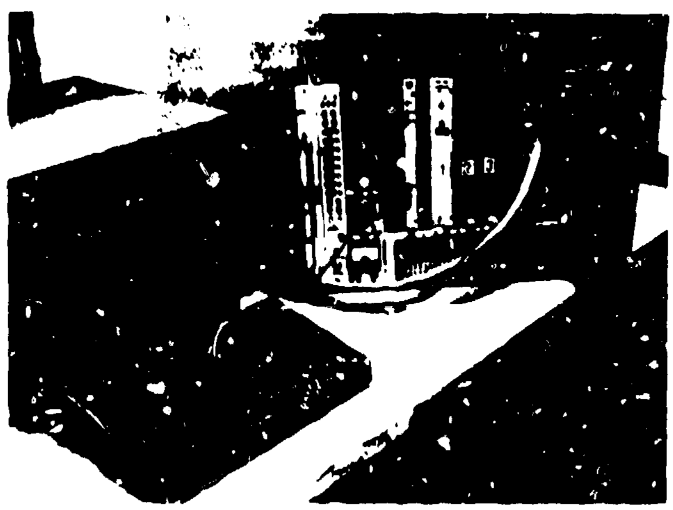

Figure 13. Interfaces to several different MCAs as well as standard modules in a CAMAC crate.

this crate through both a TTY-to-CAMAC interface and a special-design data transfer module. The automatic sample changer is connected through a dual I/O register.

The remaining crate is in the computer room. In addition to the standard modules, it contains two special modules. One is a readout unit from the Time-of-Year (TOY) clock system used in all the counting rooms and chemistry laboratories. The clock uses a WWVB receiver and provides time in Julian day-of-the-year and fraction (5 decimal places) of a day. It is used to set the computer clock at boot time. The second module is an interface to IBM 026 and 029 keypunches. Although rarely used now, it has been used in the past to provide punched card output of spectra.

EARLY COMPUTER SYSTEM

The original proposal for this data acquisition system included a PDP-11/40 with 88k words of memory, one LA30 Console, two Tektronix 4010 graphic terminals, one RK05 disk drive, two DECtape drives, a paper tape reader/punch and two IBM 729 7-track magnetic tape drives. This configuration was based on one proposed for LAMPF data acquisition systems.[9] Very rapidly the need for the three CRT consoles and two additional RK05 disk drives appeared, and they were purchased. The DECtapes and paper tape system were purchased since they were the then- available system software distribution media and also the only means for intercomputer software distribution.

As use of the DAS increased , the need for a printer/plotter and a full 256k-byte memory developed. With these items added to the system, the use and useability of the system further increased. This is shown in Figure 14.

Before long, two of the RK05s were needed just for the operating system and locally written data acquisition programs. This left only one disk drive to be shared by all users for their programs and data. Also, much of the data came from off-line MCAs via 7-track 556-bpi magnetic tape. With the low data density on the tapes and the unreliability of the old tape drives, it was apparent that changes had to be made. As a result, the magnetic tape drives on the DAS and the off-line MCA tape drives were converted to 9-track. Also a 40M-byte disk drive was purchased.

During this period, we also had problems due to the inability to add a floating point processor to the PDP-11/40. In particular, we could not easily do double precision (32-bit) integer operations, and floating point operations were done in software, which is considerably slower than hardware. Since another group within the laboratory was interested in trading PDP-11/34s to get PDP-11/40s, we traded and immediately added a floating point processor to the new central processor.

CURRENT COMPUTER SYSTEM

After a few more years, we ran into problems with not enough memory. The full 256k bytes on the PDP-11/34 was not enough to run more than a few data acquisition and analysis programs at the same time. At that time, the PDP-11/44 was announced, so we ordered one. We also ordered a second 256k-byte memory board. Once again, cpus were swapped while keeping all the peripherals. A diagram of the current system is shown in Figure 15 and a photo of the system is shown in Figure 16.

Different terminals are used for different purposes. The TEC terminals are distributed as seen in Figures 12 and 13, one in each counting room with a CAMAC crate, for use by experimenters to control data acquisition. The two 4010s are in the computer room for use in data analysis and software development. The VT100 is also used for data analysis and software development. The LA38 is a hard-copy system console.

Other peripherals include the MBD[10] to connect the Unibus to the CAMAC branch highway, and a printer/plotter. In addition to being used for various types of listings, the printer/plotter can be used to obtain hard-copy output from the 4010s and to produce plots of γ-ray spectra and of decay curve resolution of counter data.

As a result, this system has a large variety of peripherals, perhaps too many for good system reliability. The DECtapes currently are rarely used. For several years, the paper tape hardware was rarely used. However, because of the PDP-11/03 connection through CAMAC and because it had no mass storage device, it was being used for high speed reading of diagnostics for the PDP-11/03. Now, an RK05 has been moved to the PDP-11/03, so the paper tape system is no longer needed. With the addition of the large disk system to the DAS, the use of the RK05s, has greatly decreased, but they are still used for data storage for individual experimenters, for program and data transfers between computers, and for the operating system while backing up the big disk to magnetic tape. So, although use of many of the peripherals has decreased, some are still occasionally needed.

SYSTEM SOFTWARE

The software to operate the DAS comes from four general sources. The first is DEC. We have recently upgraded to RSX-11M and FORTRAN-77. This upgrade was delayed by the upgrading of "Q" and then by the heavy use of the DAS for current experiments.

Another source of our software is Versatec. This is to provide the plotting software for our printer/plotter.

The remaining two sources are basically in the laboratory. In addition to the "Q" data acquisition and analysis system, the software group at LAMPF also provides a number of programs such as PMP, SRD, and others from the RSX SIG tapes as well as some locally written software for copying magnetic tapes and debugging the CAMAC system. Another group in the laboratory provides the TEDI editor/formatter[11] which we use for editing and word processing.

The last source is locally written software. With the number of different counting systems in use, several different programs have to be used simultaneously in order to control the data acquisition. In addition, experimenters would like to process their data as it is taken, instead of doing it later either here or at their home

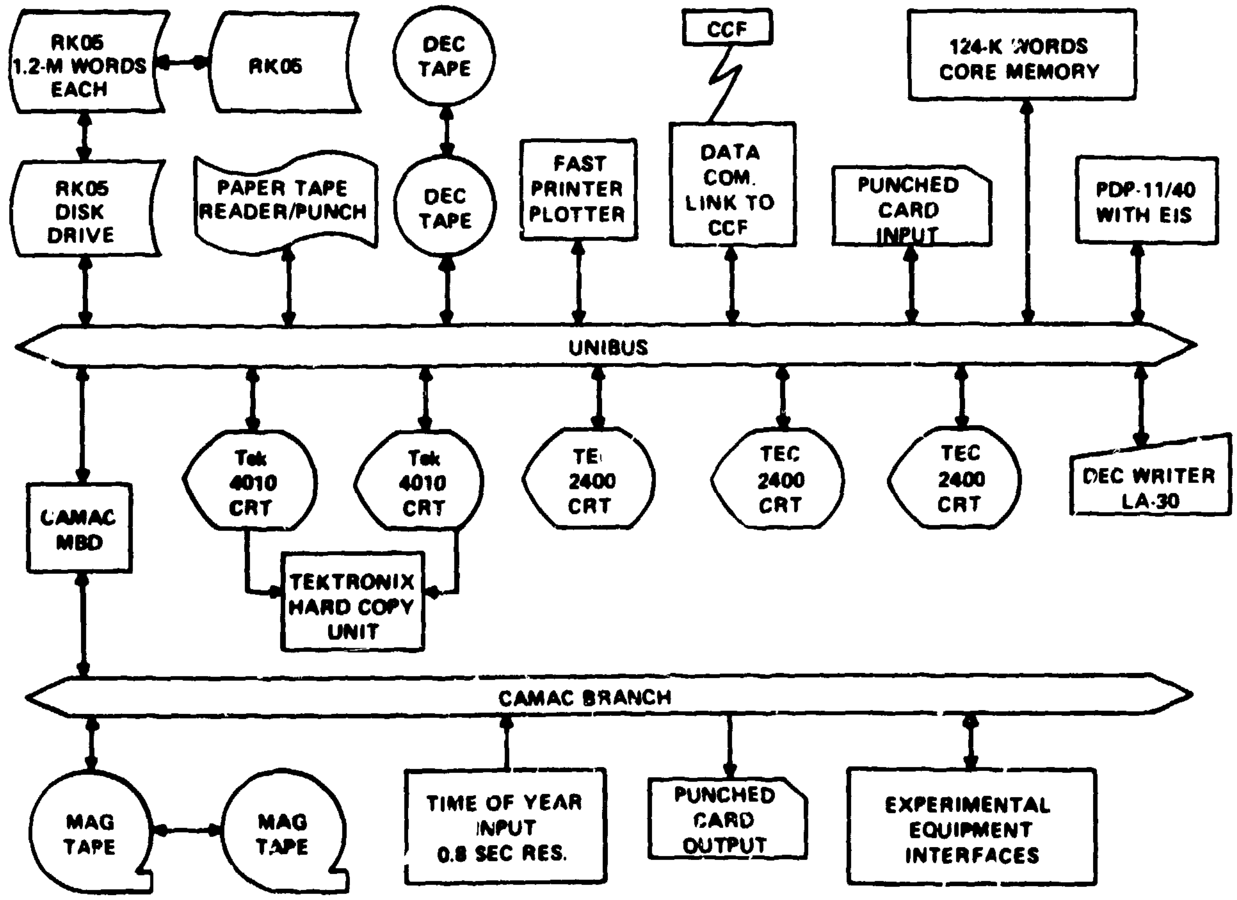

Figure 14. The early Data Acquisition Computer System.

laboratories in the case of vistors. Another use of this system is the development of software for on-line experiments using the "Q" system.

Data acquisition programs can be separated the same way as counting systems. One program controls all the scaler-timers independently in the two counting rooms. This and associated programs can be used to set up a schedule of different count lengths to be used to follow the decay of a sample. This can be done independently for each counter.

Since we have several different types of MCAs, we have different programs to handle each type. Some are used just to transfer data collected previously and stored on magnetic tape. Others are used to control on-line acquistion by the MCAs similar to the methods used for the scaler-timers and for controlling the automatic sample changer as well.

Processing the various types of data requires a number of different programs. Operations may be consolidated into several large, multifunction programs or into many smaller programs depending on personal preference and program size. Some functions which can be performed include listing and plotting of data, editing the data files in order to add to or to correct the information in them, and analyzing the data to provide the activity levels of the radioactive species at some desired time. The editing program for the scaler-produced data can also be used to create data files for counting recorded by hand. Automatic processing of the data as it is read out from a counting system and stored on disk is also possible, although not currently implemented. All of the data are stored in one of two standard formats, one scaler data, the other for spectra data.

TYPICAL OPERATIONS

The typical operation of the scaler-timers and the MCAs are very similar. An experimenter goes to the terminal in the counting room and runs the program for the counting system of interest, if it is not already running. Information about the sample to be counted, including count lengths and number of countings is entered into the file for the particular counter. A request to start the counter is initiated by use of a front panel interrupt on the Event Trigger module. If the counter is already active from the previous sample counted on it, the experimenter is asked if the restart is

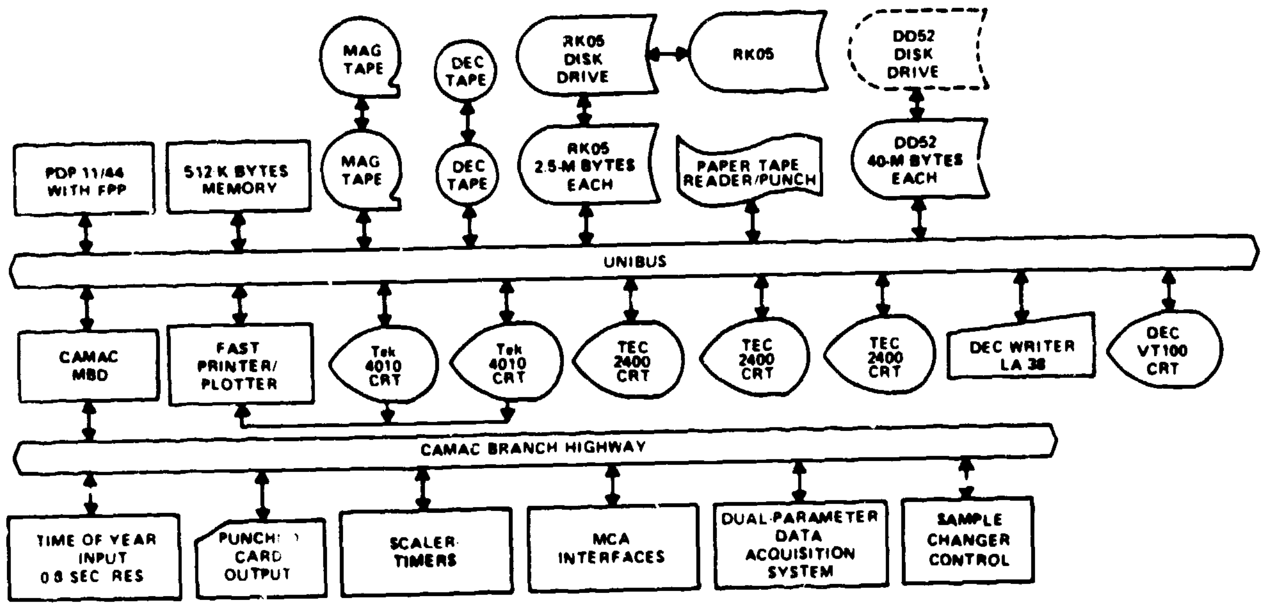

Figure 15. The schematic diagram of the current NCL Data Acquisition Computer System.

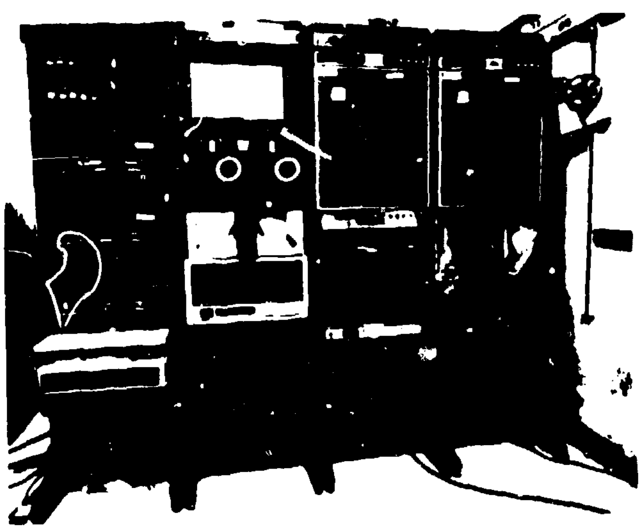

Figure 16. A photo of the Data Acquisition System.

desired to prevent accidental restarting of the wrong counter. After starting the counting system, the program goes into a wait state.

When the count is finished, a LAM is set which in turn sets a channel in the Event Trigger module and its LAM. The program determines which counter is finished by which channel is set. The data are read out, and the counter is cleared. From the counter information file, the program determines if more counts are to be taken. If so, the counter is restarted. If not, a message that the counter is finished is output to the terminal. In either case, the program then goes back into wait. The experimenter can either process this data now or wait until later.

In addition to planning for upgrading individual counters, spectrometers and their associated electronics, the future also includes networking the DAS to the LAMPF Computing Facility VAXs and thereby to the Los Alamos Central Computer Facility (CCF). This will allow archival data storage in the CCF mass storage facility and also use of the CCF VAXs, CRAYs, CDC 7600s and other large computers. Hardware upgrades also include replacement of the 40M-byte disk system with a 205M-byte RA60 system and more graphics terminals for data analysis. The RA60 should be in use by the time this is published, and it is another reason we upgraded the operating system to RSX-11M.

Future software developments include a continual upgrading of the programs used in order to make them more efficient and easier for the experimenters to use. Since many of the uses of the DAS are routine or repetative in nature, development of other types of software is not a major effort.

SUMMARY

The LAMPF Nuclear Chemistry Data Acquistion System is designed to provide both real-time control of data acquistion and facilities for data processing for a large variety of users. The large variety of counting systems have been described as well as their connections through a CAMAC parallel branch highway to main computer. Its hardware and software in general have been described as well as plans for the future.

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